Active Camouflage of Underwater Assets (ACUA)

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LONG-TERM GOALS

The long-term goals of this research are to develop the control methodology for active cloaking of underwater assets and the initial hardware concepts to test the proposed cloaking approach. This work is a natural extension of ONR Project N00014-02-1-0211 (Optical Variability and Bottom Classification in Turbid Waters: HyMOM Predictions of the Light Field in Ports and Beneath Ship Hulls) where the perceptibility of underwater assets was modeled.

OBJECTIVES

The initial objective of this work is to extend the existing 3-D Hybrid Marine Optical Model (HyMOM) (Reinersman and Carder 2004; Carder et al, 2005; Carder and Reinersman, 2007) to determine the three-dimensional light structure of representative marine environments in order to calculate the character of the radiance field needed to remove asset contrast with the background. A secondary objective is to develop a practical method to provide the additional radiance necessary to accomplish this task and to make the asset "self-aware" of its background contrast. Only in this manner will the asset be able to change radiance fields with environmental conditions.

APPROACH

Our approach rests on the foundation of our knowledge of how light interacts with water and the bottom and how it is spectrally and spatially transformed before it can become water-leaving radiance L_u. The mechanism for actively controlling submarine "cloaking" will be to use our 3-D Hybrid Marine Optical Model (HyMOM) to understand the spatial structure (e.g. Q factor, etc.) of various natural waters and a measurement methodology to control the brightness of light sources strategically placed to minimize contrast. The importance of this predictive knowledge is significant since L_u is the background from which a submerged object needs to be distinguished by an in-water or air-borne sensor, and the amount of infilling of upwelling radiance occluded by a submersible (e.g. AUV; SEAL Delivery Vehicle) will need to be added to that fraction of down-welling irradiance reflected up from the vehicle. Armed with that predictive knowledge, we propose to demonstrate that hybrid, electro-optic "chromaphotophores", that is, spectral-photophores can be utilized to provide active cloaking, and that the asset can be made "self aware" of its contrast relative to the background. HyMOM will be

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used to size and distribute light sources of the proper angular output to render the asset imperceptible by aircraft sensors.

WORK COMPLETED

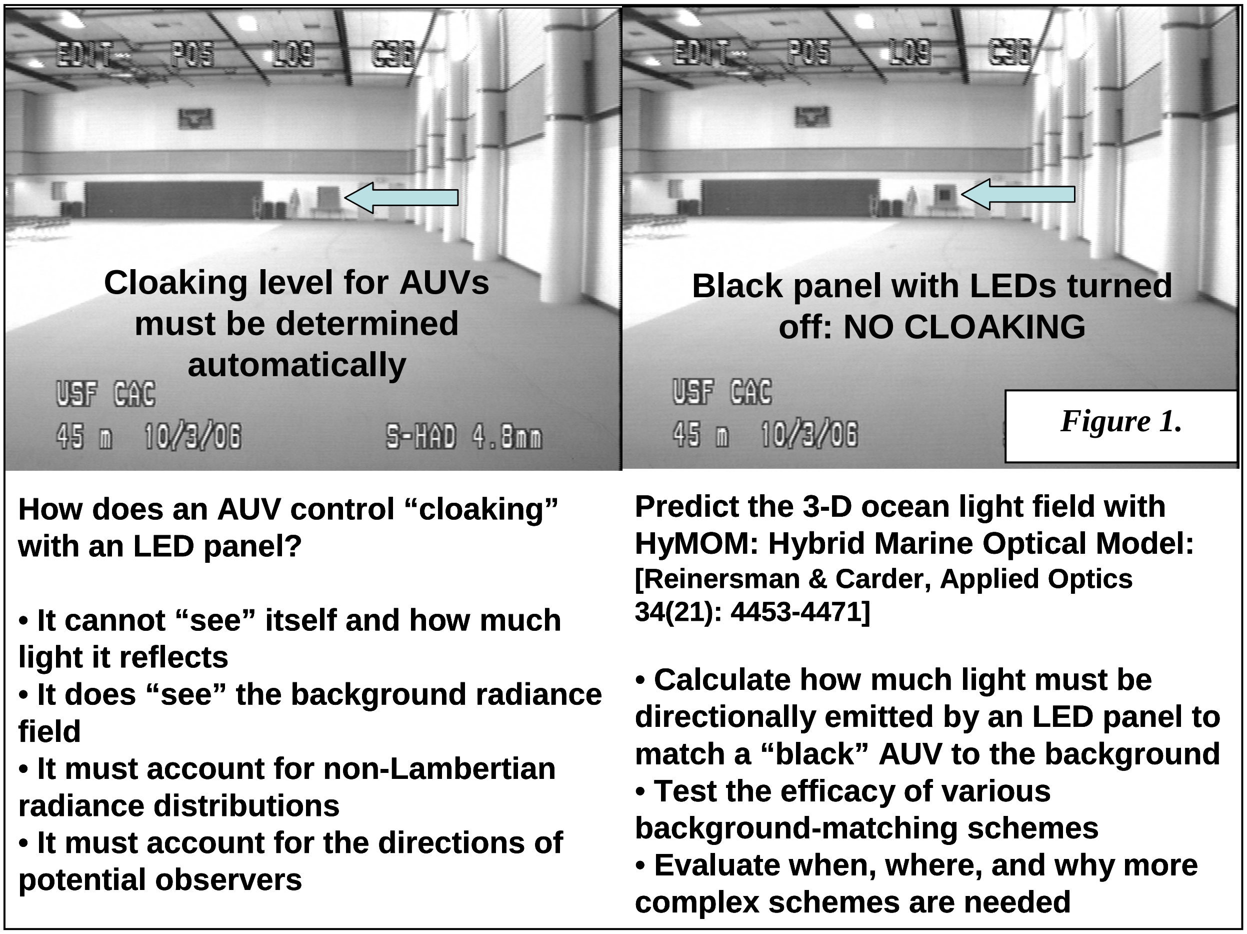

Figure 1. Sub-aerial demonstration that radiant sources properly placed and illuminated can render a black panel invisible relative to a grey background.

We have built a laboratory cloaking device to begin to identify the problems to be overcome prior to applying the method to underwater assets (Fig. 1). It provides a clear demonstration that radiance of the panel be adjusted to eliminate the contrast of a black panel overlying a grey background. The contrast adjustment was simply to increase the radiance levels on the panel until they matched the background as viewed by a remote video camera. All adjustment, however, was manual. The message is that an AUV or other submerged asset will have no remote means (e.g. remote camera) of evaluating its degree of perceptibility from various directions and locations and automatically adjusting its radiant output. Optical measurements from the asset will be used HyMOM to estimate how much radiance infilling of a black object is required to achieve asset cloaking.

Active camouflage problem. We have begun a HyMOM investigation into a simple technique of active camouflage: replacement of upwelling light obscured by the object using a discrete array of point sources attached to the upper surface of a submerged object. In this preliminary work we have considered the nearly nadir view of a cylindrical object described in the previous section. In this case, the object was modeled as black, perfectly non-reflective. The top of the object was located 1.5 m below the surface.

Camouflaging this object using static techniques may be possible in an unchanging environment. The static coating would have to be determined by a very specific shading algorithm designed not only to match theoretically predicted static conditions, but also aimed at camouflage from a specific point of view. It appears that static techniques will be applicable only for concealment from above, or from lateral views from above the horizontal. It seems clear that no passive reflective coating is going to be sufficient to reduce the contrast of the object when seen from the side or from below. There simply will not be enough upwelling ambient light available for replacement of the obscured downwelling irradiance.

The preliminary work described above leaves no doubt that static camouflage techniques will not be adequate to conceal this object in varying conditions. Any change in illumination, bottom albedo, optical characteristics of the water column, or depth of emersion will defeat static camouflage. Therefore, successful concealment of mobile underwater assets will require active and rapid adaptation of the asset to ambient conditions.

Many factors contribute to the susceptibility of this object to optical detection from above. The largest factor in this case is the contrast between the object and the background in which it is embedded. This contrast stems from the occlusion of upwelling light from beneath the object coupled with the complete lack of reflectance of down-welling light incident on the object's upper surface. In this preliminary work we have not addressed other factors such as the shadow of the object casts onto the sea bottom, or the darkened shaft of light between the object and its shadow.

In order to reduce the contrast between the object and background we have modeled an array of point sources attached to the upper surface of the object. For computational simplicity in the initial work, the light sources are not attached directly to the curved surface of the object, but are arranged in a horizontal planar array at the same depth as the object's upper centerline. Conceptually, this corresponds to a transparent, horizontal flat plate attached to the object, tangent to the object along the center line of the upper surface. This conceptual plate has the same dimensions as the horizontal extent of the object, i.e., 0.5 m wide by 6.0 m long.

It is to this transparent flat plate that the array of point sources is attached. Point sources are arranged on a rectangular grid, 0.0625 m between centers, and are characterized by a Lambertian emission pattern with a conical half-angle of 50°. The sources were adjusted individually using a simple iterative process which reduced local contrast in the region of the image influenced by the respective source. Convergence to the state shown required only 10 iterations and could easily be implemented to run continuously in real time. While this model scenario does not match exactly the constraint of having the lights attached to the upper surface of the cylindrical object, nor does it match exactly an object having a flat upper surface, the results obtained are believed to be indicative of the potential of active camouflage techniques. Figure 2 shows both objects (natural and camouflaged) in the same scene when viewed from above. The block-like noise in the image results partially from using simulations which had not quite converged. More significantly, the image intensity has been scaled and stretched to increase apparent contrast. With no stretch, the image the object on the right is indistinguishable from the background.

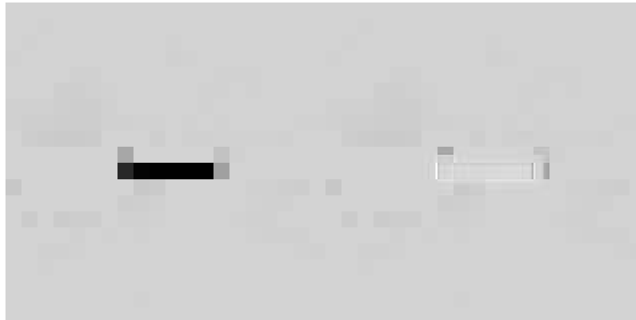

Figure 2. Two submerged cylindrical objects viewed from above. Scene dimensions are 10 m by 20 m. Both objects are non-reflective. Object on right is beneath an array of appropriately adjusted point sources.

Validation problem. In order to remotely observe an underwater asset and determine the conditions under which it becomes "invisible" to the method of detection, we are using assets available from the USF College of Marine Science Center for Underwater Observability and Optical Communication. These consist of a 37' boat, a remotely operated vehicle (ROV), and an aerostat. Various video and digital still cameras on the aerostat will be remotely controlled from the boat to view the ROV with a radiant panel placed above it (see Figs. 3 and 4). The ACUA project commenced 1 May 2007, and the Center funding began shortly thereafter. Most components have been purchased and assembly has begun on all components of this validation effort. Inherent and apparent optical properties will be measured from the ROV to provide inputs to the HyMOM model and for use with a local optical perceptibility system above the panel. The combination will be used to improve the cloaking strategies available to an autonomously operated asset. These systems will be used to acquire data for ROV deployments at various depths over a variety of bottom types under differing lighting conditions. HyMOM will be used to improve operational strategies from both detection and camouflaging perspectives.

IMPACTS/APPLICATIONS

The Hybrid Marine Optical Model has been applied to evaluating the 3-D light field beneath ships, around pilings, around mine-like objects, and around AUVs at various depths. It has also been used to prescribe the active light field necessary to "cloak" underwater assets from daylight observation by aircraft or sub-surface observations. These results can be used to impact search strategies for underwater mines, AUVs, and mini-submarines, and to guide the application of active camouflage to "cloak" U.S. underwater assets.

RELATED PROJECTS

- USF College of Marine Science Center for Underwater Observability and Optical Communication: Kendall L. Carder and David K. Costello, P.I.s. This project provides the boat, ROV, and aerostat with associated instrumentation to initialize HyMOM model runs and validate the effectiveness of various cloaking approaches.

- SRI International: John Bumgarner and Eric Kaltenbacher are providing MEMs-based "cloaking" panels as a subcontract to USF.

- Coastal optical data sets for coastal Florida and Bahamas waters (see references) were collected by various past ONR and NASA projects of K.L. Carder, especially ONR project N00014-02-1-0211 (Carder and Reinersman), which has transitioned into ACUA. Studies in modeling and measuring seawater optical properties were funded by ONR #N000140-02-1-0211 "Optical Variability and Bottom Classification in Turbid Waters: Phase II" and #N00014-03-1-0177 "Distribution of our CoBOP Results: IOPs and Albedo Spectra for Incorporation into Radiative Transfer Models." Ambient light condition modeling was funding by ONR #N00014-03-1-0625 "A Hybrid Modular Optical Model to Predict 2-D and 3-D Environments in Ports and Beneath Ship Hulls for AUV Sensor-Performance Optimization in MCM Activities."

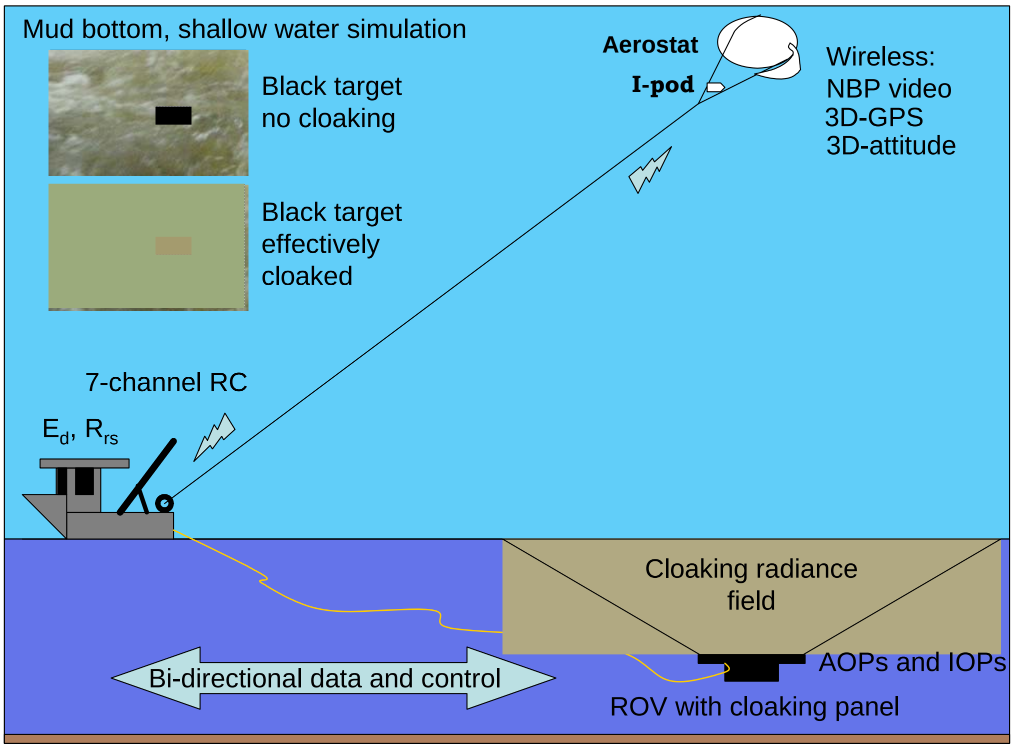

Figure 3. Cartoon showing envisioned field experiment strategy. The R/V Subchaser will act as the mother-ship for our airborne and underwater remotely operated vehicles. Without the aerostat (TOPO-13), field operations would be prohibitively expensive.

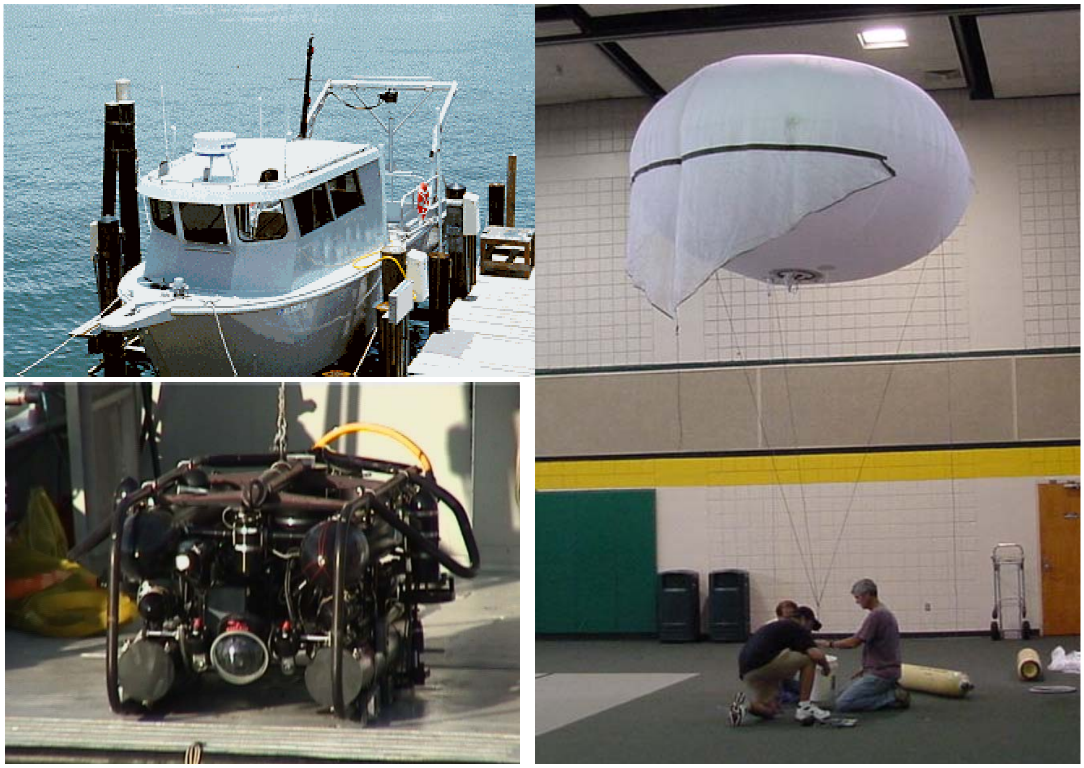

Figure 4. The R/V Subchaser (upper left) will support) two remotely operated vehicles for field operations. The ROSEBUD ROV (lower left) will carry a modulated LED array and make AOP and IOP measurements. The 13-foot Tethered Observability Platform for Oceanography (TOPO-13, right) will observe the ROV from various altitudes and acquire spectral data.

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PATENTS

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